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14. ABSTRACT
The proposed project aims to develop a fundamental framework for establishing an immersive virtual reality environment for robust and scalable human robotics interaction in a cooperative intelligent architecture at the University of Houston-Victoria, a designated Hispanic Serving Institution of higher education. The requested equipment and instrumentation will be integrated into our currently established motion capture facility and will serve as a complement system to augment our currently active research and educational capabilities in animation, virtual reality, and computer vision.

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## Report Title

Final Report: Immersive Virtual Reality with Applications to Tele-Operation and Training


## ABSTRACT

The proposed project aims to develop a fundamental framework for establishing an immersive virtual reality environment for robust and scalable human robotics interaction in a cooperative intelligent architecture at the University of Houston-Victoria, a designated Hispanic Serving Institution of higher education. The requested equipment and instrumentation will be integrated into our currently established motion capture facility and will serve as a complement system to augment our currently active research and educational capabilities in animation, virtual reality, and computer vision.

Furthermore, the resulting integration provides new and exciting avenues of research in multi-agent virtual reality and robotics as well as stimulating educational tools to engage more under-represented students in STEM Fields. The population of graduate and undergraduate students within the Digital Gaming and Simulation, Computer Science programs will actively collaborate with the PI and Co-PIs to integrate the equipment into our current facilities and to engage in several research projects to establish the proposed computational architecture. These projects aim to study, assess, and reconfigure suitable visualization and HCI tools for the proposed integrated virtual reality environment for the human-robotics interactions.


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## Enter List of papers submitted or published that acknowledge ARO support from the start of the project to the date of this printing. List the papers, including journal references, in the following categories:

### (a) Papers published in peer-reviewed journals (N/A for none)

Received Paper

**TOTAL:**

**Number of Papers published in peer-reviewed journals:**

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### (b) Papers published in non-peer-reviewed journals (N/A for none)

Received Paper

**TOTAL:**

**Number of Papers published in non peer-reviewed journals:**

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### (c) Presentations

**Number of Presentations:** 1.00

## Non Peer-Reviewed Conference Proceeding publications (other than abstracts):

| Received | Paper |
|---|---|

**TOTAL:**

**Number of Non Peer-Reviewed Conference Proceeding publications (other than abstracts):**

## Peer-Reviewed Conference Proceeding publications (other than abstracts):

| Received | | Paper |
|---|---|---|
| 02/03/2016 | 2.00 | Brandon Wilson, Matthew Bounds, Alireza Tavakkoli. Hand Motion Calibration and Retargeting for Intuitive Object Manipulation in Immersive Virtual Environments, Procdeedings of the IEEE Virtual Reality Conference. 19-MAR-16, . : , |
| 12/01/2015 | 1.00 | Brandon Wilson, Alireza Tavakkoli. An Efficient Non-Parametric Background Modeling Technique with CUDA Heterogeneous Parallel Architecture, Interntaional Symposium on Visual Computing. 14-DEC-15, . : , |

**TOTAL:** **2**

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## (d) Manuscripts

| Received | Paper |
|---|---|

**TOTAL:**

**Number of Manuscripts:**

## Books

| Received | Book |
|---|---|

**TOTAL:**

| Received | Book Chapter |
|---|---|

**TOTAL:**

## Patents Submitted

## Patents Awarded

## Awards

UHV Internal Research Award: Immersive Virtual Reality for Telerobotics (September 2015)

## Graduate Students

| NAME | PERCENT_SUPPORTED | Discipline |
|---|---|---|
| Matthew Bounds | 0.00 | |
| Peter Hu | 0.00 | |
| Brandon Wilson | 0.00 | |
| **FTE Equivalent:** | **0.00** | |
| **Total Number:** | **3** | |

## Names of Post Doctorates

| NAME | PERCENT_SUPPORTED |
|---|---|
| **FTE Equivalent:** | |
| **Total Number:** | |

## Names of Faculty Supported

| NAME | PERCENT_SUPPORTED | National Academy Member |
|---|---|---|
| Alireza Tavakkoli | 0.00 | |
| Donald Loffredo | 0.00 | |
| Li Chao | 0.00 | |
| **FTE Equivalent:** | **0.00** | |
| **Total Number:** | **3** | |

## Names of Under Graduate students supported

| NAME | PERCENT_SUPPORTED | Discipline |
|---|---|---|
| David McFadden | 0.00 | |
| Melissa Clark (URAP Summer Inte | 1.00 | |
| Lucas Kabela (HSAP Summer Inte | 1.00 | |
| Brandon Wilson | 0.00 | |
| **FTE Equivalent:** | **2.00** | |
| **Total Number:** | **4** | |

## Student Metrics

This section only applies to graduating undergraduates supported by this agreement in this reporting period

The number of undergraduates funded by this agreement who graduated during this period: ...... 1.00

The number of undergraduates funded by this agreement who graduated during this period with a degree in science, mathematics, engineering, or technology fields:...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will continue to pursue a graduate or Ph.D. degree in science, mathematics, engineering, or technology fields:...... 1.00

Number of graduating undergraduates who achieved a 3.5 GPA to 4.0 (4.0 max scale):...... 1.00

Number of graduating undergraduates funded by a DoD funded Center of Excellence grant for Education, Research and Engineering:...... 0.00

The number of undergraduates funded by your agreement who graduated during this period and intend to work for the Department of Defense ...... 1.00

The number of undergraduates funded by your agreement who graduated during this period and will receive scholarships or fellowships for further studies in science, mathematics, engineering or technology fields:...... 1.00

## Names of Personnel receiving masters degrees

| NAME |
|---|
| **Total Number:** |

## Names of personnel receiving PHDs

| NAME |
|---|
| **Total Number:** |

## Names of other research staff

| NAME | PERCENT_SUPPORTED |
|---|---|
| **FTE Equivalent:** | |
| **Total Number:** | |

## Sub Contractors (DD882)

## Inventions (DD882)

## Scientific Progress

The acquired equipment is used in engineering, developing, and evaluating systems that utilize mathematical and computational tools to help enable us efficiently interact with the world around us or in our imagination. To this end, our research team investigates the use of artificial intelligence and visual computing. Numerous fields across the human-computer interaction and gaming research areas, form modeling to visualization, rely on the foundations within this cross-section of computing sciences. The projects for which the equipment is utilized serve as a potentially unique bridge at the intersection of two domains. On the one hand a significant amount of research has been invested in digital gaming and simulation to cognitively stimulate humans by computers, resulting in a $10.5 billion entertainment industry [1]. On the other hand, cognitive computing scientists and roboticists are engaged in developing computational models to enable computers and robots understand physical and cyber environments efficiently.

We believe that connecting these domains through an intelligent and immersive virtual reality environment will enable the discovery of novel paradigms for establishing a more responsive man–machine cooperation. Drawing from the above two conversations may help answer questions that are fundamental to each. For artificial intelligence researchers, the question is: What would make an artificially intelligent agent more aware of the environment and its users' motives and intentions? For game designers, the question is: What motivates and draws players to engage with game agents to perform a mutually beneficial and complex objective?

The establishment and continuation of this research will make significant impacts on a variety of applications in which human operators need to be in communication with and control of cyber-physical systems, when such systems need to maintain a sufficiently high level of autonomy. This efficient human–robot–environment interaction and its associated operations become more important when viewed from the perspective of computational efficacy and deployment experiences to support a mission and its objectives.

Detailed Report on Scientific Progress and Accomplishments as well as the utilization of the acquired equipment is outlined in the attachment(s) below.

## Technology Transfer

# Final Report

Period of Performance: December 8, 2014 – December 7, 2015
By: Alireza Tavakkoli (PI)

## Foreword

The acquired equipment from this award is used to engineer, develop, and evaluate systems that utilize mathematical and computational tools to help enable us efficiently interact with the world around us or in our imagination. To this end, our research team investigates the use of artificial intelligence and visual computing. Numerous fields across the human-computer interaction and gaming research areas, form modeling to visualization, rely on the foundations within this cross-section of computing sciences. The projects for which the equipment is utilized serve in developing a potentially unique bridge at the intersection of two domains. On the one hand a significant amount of research has been invested in digital gaming and simulation to cognitively stimulate humans by computers. On the other hand, cognitive computing scientists and roboticists are engaged in developing computational models to enable computers and robots understand physical and cyber environments efficiently.

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# List of Figures and Illustrations

# Statement of Problem Studied

The equipment is currently being utilized in conducting research in addressing an over-arching question: How can we develop a framework capable of merging an artificially intelligent environment with an immersive virtual one, in a manner that both environments become aware of their user's motives and intentions, while drawing the human operator to intuitively engage with the environment and its agents? In order to answer this question, we are developing a cyber-physical environment capable of perceiving both users' and robotic agents' actions from the real world and within the virtual environment, while processing this information to act accordingly upon the virtual environment and on the real world. The research activities and process flow between the research components in our framework for the integration of intelligent physical environments with an immersive virtual one are depicted in Figure 1. There are two main research motifs; an efficient computational framework for Virtual Reality and Tele-robotics, and the associated human studies in validating the performance and efficacy of the framework.

The first motif is comprised of three research tasks, of which the first two (VRT-1 and VRT-2) are interconnected. The objective of these two tasks is to help build reliable models in order to facilitate information depth and immersion (human's perception) as well as information breadth and interactivity (system's perception). First, there is the problem of modeling interactions between user, environment, and robot from data supplied by a multitude of sensory devices. To approach the issues of breadth of information and interactivity (VRT-1) we rely on robotics and machine learning. On the other hand, we have the problem of the human's perception of the agent's situation and its environmental conditions. This problem is approached from the perspective of the digital gaming field (VRT-2).

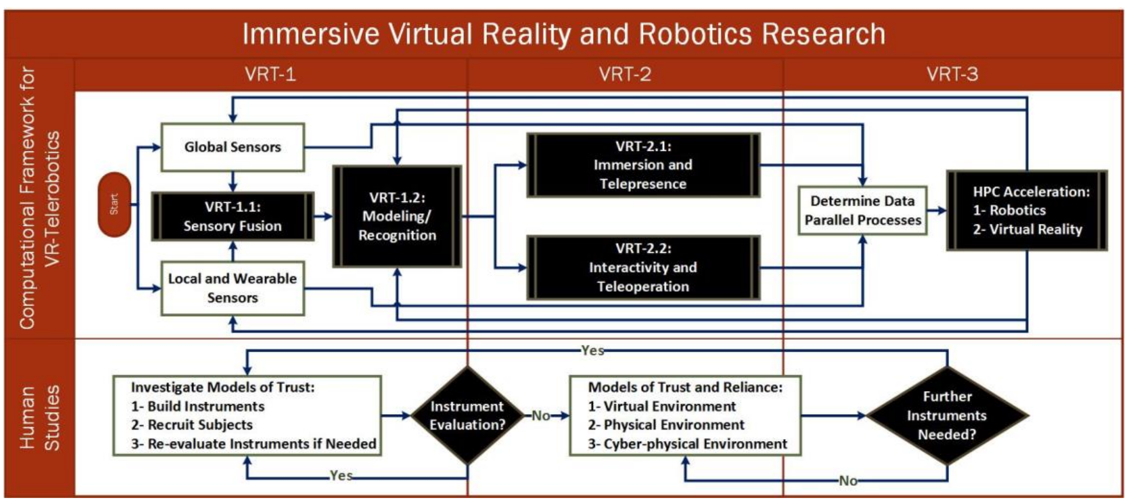



*Figure 1. Main Research Activities*

The third research task (VRT-3 in Figure 1) in support of this computational platform is to enhance the processing power of the framework and to free on-board computational needs on both robotic agents and the virtual reality components. To achieve this objective we are studying and developing data parallel algorithms for the data parallel processes used across the system. This computation targets NVidia's CUDA heterogeneous computing platform and is currently being performed on servers based on NVidia's Kepler architecture. We showed performance increases of up to 2 orders of magnitude with the acceleration of foreground object detection in our global visual sensory systems [12].

To improve human user's visual and auditory stimulation we utilize head-mounted displays, immersive sound systems, and the Virtuix's Omni, the first virtual reality interface that allows for the player to move freely and naturally in virtual environments. Our platform of choice for the implementation of the virtual reality environment is the Epic Game's Unreal Engine 4 [13]. To achieve the goals of the VRT-2 track, we address two problems: (VRT2.1) to create an immersive experience and (VRT2.2) to enhance interactivity with the virtual world. Our first results of integrating fine-grain finger movements acquired from Leap Motion sensors with the body kinematic motion from our Vicon system will be discussed at the 2016 IEEE Virtual Reality conference [14].

# Summary of Most Important Results

The proposed study is situated at the intersection of two conversations. On the one hand, scholars in digital gaming and simulation are researching the burgeoning world of video games, an industry that has penetrated two-thirds of United States households and now constitutes a $10.5 billion industry. On the other, roboticists tirelessly engage in developing computational models to bring physical objects to life, safely and efficiently, in and around humans.

Entertainment gaming researchers and engineers have given much attention to developing technological advances aimed at drawing humans more and more into the game world, through head mounted displays, 3D body tracking sensors, and haptic user interfaces. In a parallel and equally exciting area of research, robotics and artificial intelligence scholars have been investigating theoretical and algorithmic frameworks to make robots work safely and effictively in the real world, in military, industrial, medical, and domestic applications.

The equipment acquired by this award is utilized in a number of projects with the goal of developing two environments: a physical, intelligent environment comprised of unmanned autonomous agents and multiple layers of static and dynamic sensors, and its virtual replica in which human subjects (i.e. trainees and operators) will be immersed to tele-exist with their physical autonomous companions for training and teleoperations purposes.

## Current Projects

The sections below describe the current projects in which the equipment is being utilized. First, the overall project will be presented. In this project a unified framework for the integration of heterogenous robotic agents within an immersive virtual reality environment is developed.

The second project discusses the acceleration of visual capabilities for the proposed framework on many-core systems for the purpose of detecting objects of interest within the unified framework. This project shows the process and results of such accelerations in speeding up the overall computer vision task at hand.

The third project presents a mechanism for integrating and calibrating human hand and finger moevements within the proposed virtual reality framework. This will enable human operators to intuitively communicated with the robots through gestures by integrating two motion capture systems, i.e. Vicon body motion capture and Leap Motion hand motion capture.

## ArVETO: An Aria-Based Client-Server Architecture for the Integration of Autonomous Robotic Platforms and Remote Users in a Virtual Reality Environment

In this project an architecture is designed to integrate a number of robotic platforms in interactive immersive virtual environments. The architecture, termed ArVETO (*Aria Virtual Environment for Tele-Operation*), is an Aria-based client-server architecture that communicates directly with a state-of-the-art game engine to utilize a virtual environment in support of tele-robotics and tele-presence.

This framework employs the Unreal Engine 4 (UE 4) to provide the front-end virtual environment and user controls, while utilizing a comprehensive networking architecture to handle communications between the robots, user clients, and our computational server. In order to accelerate data-intensive computations in support of such an interactive and immersive environment, we utilize the CUDA toolkit and OpenCV libraries to handle any calculations needed on the computational server, as well as common image processing tasks. The strength of the proposed architecture is that it allows for the integration of heterogeneous robotic systems in an intelligent immersive environment for intuitive interactions between the robot and its operators.

By utilizing an immersive virtual reality medium, an operator can more naturally interact with the robot; as buttons and joysticks can be replaced with hand gestures and interactions with the virtual environment. This provides a higher degree of immersion and interactivity for the operator when compared to more traditional control schemes.

### *The Proposed Architecture*

In this section, details about an integrated architecture is presented, that allows the user to control remote robotic agents in an interactive virtual environment, while providing mechanisms for the robots to efficiently send back their sensory data to the server and subsequently the user, as shown in Figure 2. The user controls the robots in a virtual environment. This provides a more immersive experience for interacting and operating remote robots, as the operator senses the presence of the robot and its environmental conditions remotely, while interacting intuitively with the robot.

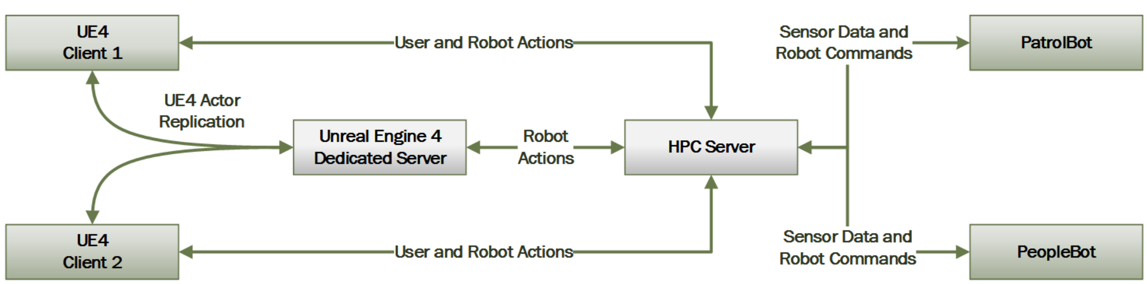



*Figure 2. An overview of the ArVETO network architecture.*

Robotic agents provide a wide range of sensors such as sonar, laser range-finders, physical bumpers, and stereoscopic cameras that gather 3D information about their environment. Integrating these sensory data into a 3D immersive and interactive virtual environment will provide much higher levels tele-presence and immersion for control and operation of remotely situated robots. In the purposed architecture a centralized computational server is utilized in order to mediate the communication between the Virtual

Reality (VR) client and the robot client, while performing data-intensive computations required for the proposed architecture and its several components.

The proposed integrated architecture, called ArVETO (*Aria Virtual Environment for Tele-Operation*), supports the computations essencial for tele-robotics and tele-presence, implemented within an interactive and immersive virtual reality environment. The proposed system has three major components, comprising of virtual reality clients, a centralized High Performance Computing (HPC) computational server, and a number of robotic clients – each specialized to perform certain tasks. This framework allows for multiple clients to interact with multiple robots in a virtual environment, with the ultimate goal of remotely operating the agents while allowing for high-fidelity tele-presence by the human operators. An overview of this architecture is shown in Figure 3.

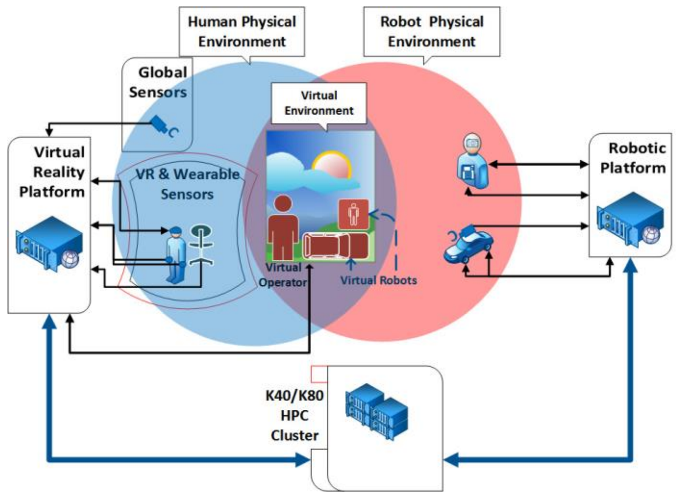



*Figure 3. An overview of the proposed framework architecture.*

The boxes on the right represent the processes performed on the physical robotic platforms, while the items on the left represent computations performed by the UE4 clients. The computational sever processes connect these two types of clients together. The robots stream raw sensory data to the computational server to be stored and processed as well as retrieved by the UE4 clients as needed. In addition, some of the retrieved data is sent to either a UE4 listen or dedicated server to utilize actor replications for streaming properties of the virtual robot – such as location, orientation, and other environmental conditions – to all of the connected UE4 clients. Afterwards, the operator can examine the state of the virtual robot and environment and send operational commands back to the robot, through the UE4 client's direct connection to the computational server and the server's connection to the robotic platform.

The benefit of the ArVETO network architecture is threefold. First, it provides a traditional client-server architecture that minimizes the network bandwidth required by reducing the total network connections and transactions required by the architecture. In addition, this server can process data-intensive computations needed in support of the entire system. These computations must be performed on the raw sensory data to potentially reduce the amount of the data needed to be sent to each UE4 client and to improve the accuracy of the UE4 virtual environment. Second, the ArVETO architecture uses UE4 actor replication, to efficiently stream the robots' properties to further reduce the network bandwidth. Finally, we utilize the concept of network relevancy. That is, each UE4 client in the ArVETO architecture communicates to the server from which robot, if any, it requests data. This allows the UE4 clients to cull robots, either because they are out of focus of the operator or because they are too far away from the virtual operator to be of significant impact. This relevancy mechanism reduces network bandwidth even further. This reduce in bandwidth is crucial, as all calculations and transactions in the ArVETO architecture are performed in real-time.

ArVETO is designed to support several projects aimed at creating an over-arching umbrella for immersive virtual reality, robust telerobotics, and interactive tele-presence systems. These projects include online 3D reconstruction and procedural generation of the physical environment, robust networked connections for the remote physical agents and virtual operators, Simultaneous Localization and Mapping (SLAM) for each of the robotic clients, a teleoperation system based upon an efficient mapping from the users actions within the virtual environment to robots actions on the physical environment, and the accurate presentation of robots actions back into the virtual environment. As such, ArVETO has been designed from the ground up with each of these tasks in mind, resulting in a versatile and generalized architecture.

### *Architecture*

As previously stated, ArVETO is comprised of three major components. Each of these components and their implementations are outlined in Figure 4, and each of them are detailed below. This figure shows how communication between UE4 and each of the Aria clients can be achieved.

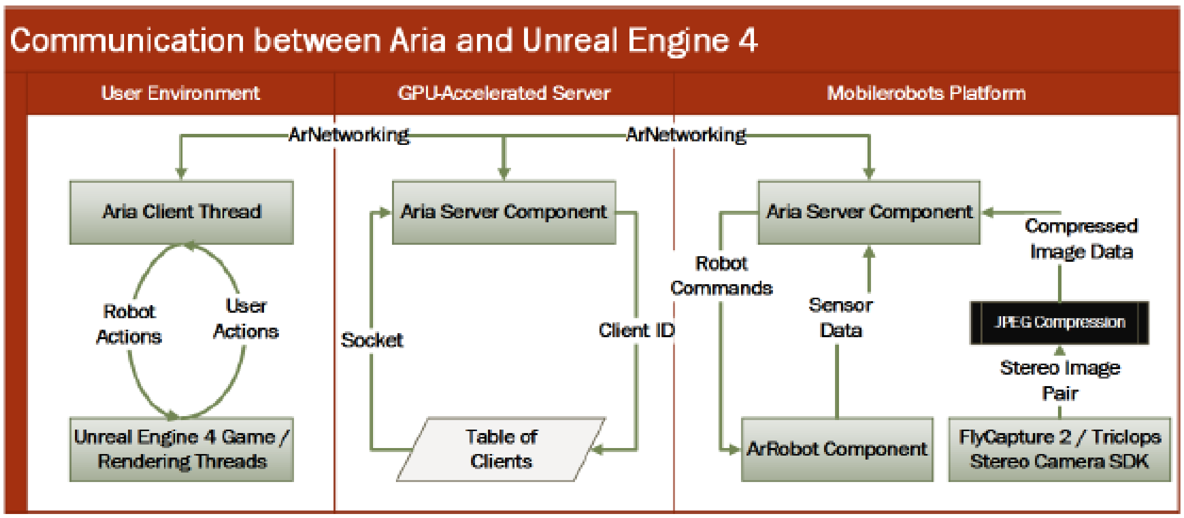



*Figure 4. Allocation of work and overall communications between the Aria SDK and Unreal Engine 4 in the proposed architecture.*

Suppose we operate one robotic client through a single UE4 client within the ArVETO architecture. From the UE4 game thread, any actions performed on the environment by the user must be sent to the Aria client thread before it can be sent to the other ArVETO network components. This Aria client is connected to the computational server as well as the robotic platform's client component. Any data sent by the UE4 client must first pass through the computational server, which can validate and process the data before it is sent to the desired robot platform. The server contains a table of clients, which can efficiently match a client ID to its current socket.

Finally, any commands that reach the desired robot are executed by communicating with the ArRobot component of the robotic platform. The robot also sends data to UE4 in a similar manner. Most sensory data are retrieved from the ArRobot component and sent to the server. However, stereo image pairs must first be retrieved from the FlyCapture 2 and Triclops pipeline and compressed using OpenCV in order to minimize the needed bandwidth.

### *Results*

With the ArVETO architecture we were able to connect the mobile robots and the VR client to the centralized server to perform remote operations and navigational tasks. This allowed us to control the robot in a virtual environment as it moved through an identical physical environment. The robot was able to successfully navigate through our virtual environment while moving through the physical world.

Figure 5 shows the physical robot in the hallway (the left image) and the virtual robot in the VR hallway (right image), respectively. The navigation of the Patrolbot was done by an operator observing the robot's location via the stereoscopic cameras on both the physical and virtual robot. Autonomous navigation by the robot can be conducted by putting the robot in autonomous mode and without user intervention. The virtual reality environment in which the robot operates is a replica of an indoors hallway with physical objects and obstacles present. This experiment showcases the differences and similarities between the teleoperated robot and the VR robot.

*Figure 5. The robot operation with ArVETO: Left- PatrolBot in the real world. Right- the PatrolBot as observed and operated in the Virtual World through Oculus Rift HMD (Head Moutned Display).*

## An Efficient Non-Parametric Background Modeling Technique with CUDA Heterogeneous Parallel Architecture

Foreground detection plays an important role in many content based video processing applications. To detect moving objects in a scene, the changes inherent to the background need to be modelled. In this work we propose a non-parametric statistical background modeling technique. Moreover, the proposed modeling framework is designed to utilize the Nvidia's CUDA architecture to accelerate the overall foreground detection process. We present three main contributions: (1) a novelty detection mechanism capable of building accurate statistical models for background pixels; (2) an adaptive mechanism for classifying pixels based on their respective statistical background model; and (3) the complete implementation of the proposed approach based on the Nvidia's CUDA architecture. Comparisons and both qualitative and quantitative experimental results show that the proposed work achieves considerable accuracy in detecting foreground objects, while reaching orders of magnitude speed-up compared to traditional approaches.

This objective of this research is to track multiple objects in videos with complex backgrounds, also called quasi-stationary backgrounds [2]. There are three main approaches in developing scene independent, non-parametric object tracking frameworks that detect and track foreground objects while disregarding background changes [3][4][5]. In order to track objects in real-time, spatio-spectral connected component processing mechanism may be utilized to employ photometric appearances of individual objects to assign them unique ID's [6].

This mechanism is suitable to be utilized in a robotic application to detect potential threats by recognizing the intent of humans present in a scene [7]. We will build on this idea to utilize robots in an environment to recognize the intent of other agents, i.e. robots and people [8][9].

### *Methodology and Approach*

In order to accelerate the foreground detection for real-time immersive virtual reality tele-robotics framework we propose a novel non-parametric approach for foreground detection, capable of exploiting parallelism available through Nvidia CUDA. Our proposed mechanism is comprised of three main stages and two optional post-process modules. Figure 6 shows the workflow utilized in the proposed framework. The update, training, and classification phases of the proposed framework in Figure 6 are represented as the lateral sections. The horizontal sections represent stages of the proposed architecture as preprocess, post-process or the detection stage.

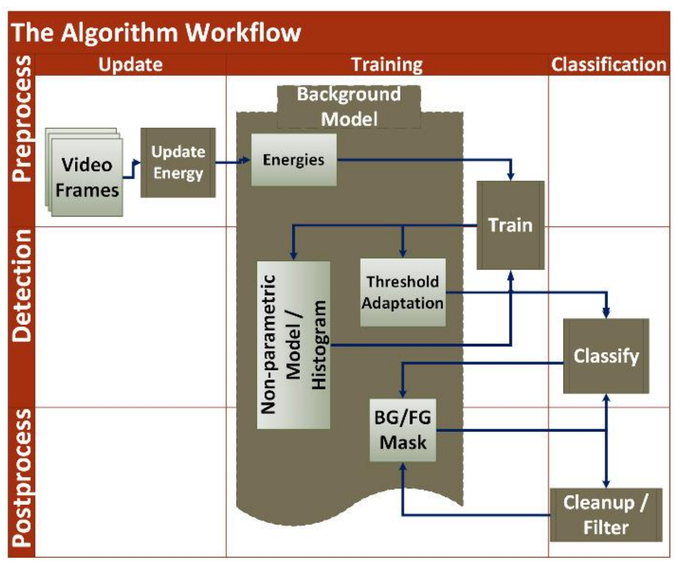



*Figure 6. Acceleration of the Vision Processes*

The first stage is an update phase, executed on every frame to update the background information based on the newly available data. This data is then analyzed in the training phase to produce a model for each background pixel in the frame. The training phase is the slowest, but only needs to be executed on a fraction of the available blocks every frame. Finally, a classification phase is executed on every frame to determine if each pixel belongs to the background or foreground using strict and loose classification criteria. Two post-process modules are also employed, in real-time, to refine the foreground detection results and remove undesirable artifacts and noise.

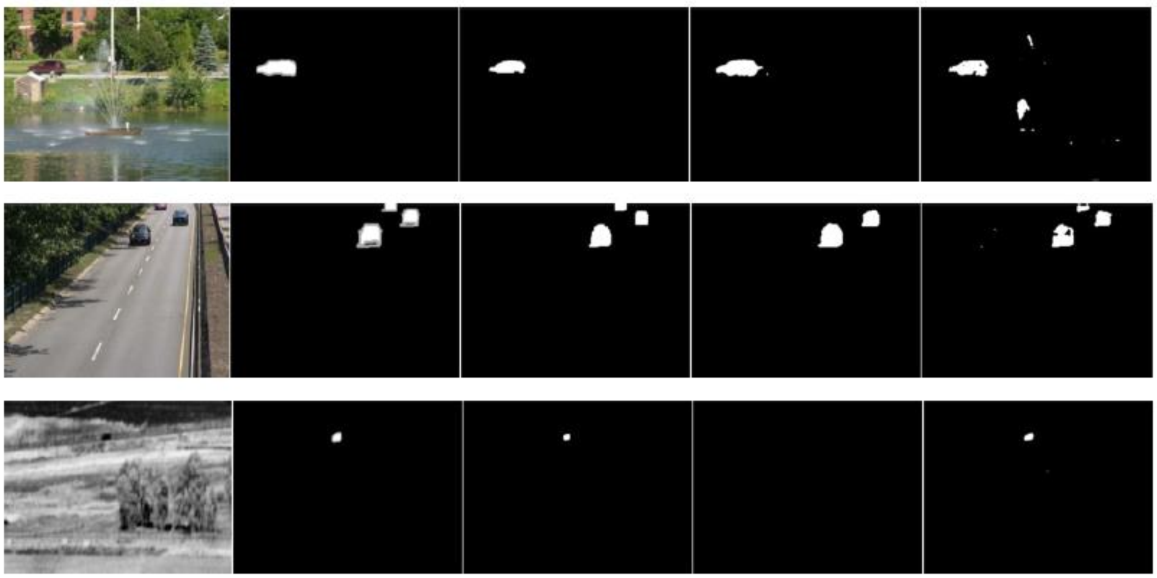


*Figure 7. Sample qualitative comparisons. From left: original frame, ground truth, detected foreground by our approach, the FTSG [16], and [17].*

### ***Experimental Results***

Qualitative and Quantitative comparisons have been made with other state-of- the-art foreground detection methods shown on the www.changedetection.net website [15]. These comparisons range from 11 categories; each containing four to six videos. Each video has been scored based on seven measurements against the ground truths provided by the changedetection.net website.

We compared our results to the original frame, ground truth, and two other state-of-the-art foreground detection methods. Figure 7 shows some of these results. Each row shows from right to left; The sequence frame, the ground truth, our proposed method's results, the FTSG [16] method's results and the Euclidean Distance method's results [17].

Our proposed method has been ranked with all of the published state-of-the-art methods of background segmentation on the changedetection.net website using all available data, and the results have been reported in [12]. These results show that our approach is comparable in quality to the traditional methods. Most of traditional methods report a processing speed at below 24 fps on a 320x240 video [15], where our algorithm has achieved a maximum processing speed of 1146 fps on the same 320x240 sequences using an Nvidia Tesla K80 cluster. The processing speeds of the top four methods based on average ranking is shown in Figure 8. The proposed method used less than 3.5% of the device on average when processing all of the changedetection videos, and we have achieved similar results on a commercial Nvidia graphics card. In comparison, the sequential version of our algorithm, using an enterprise Intel Xeon E5-2620 v3 CPU and the same parameters, processed 38 times slower on a small resolution (320x240) sequence, and 82 times slower on a large resolution (720x480) sequence.

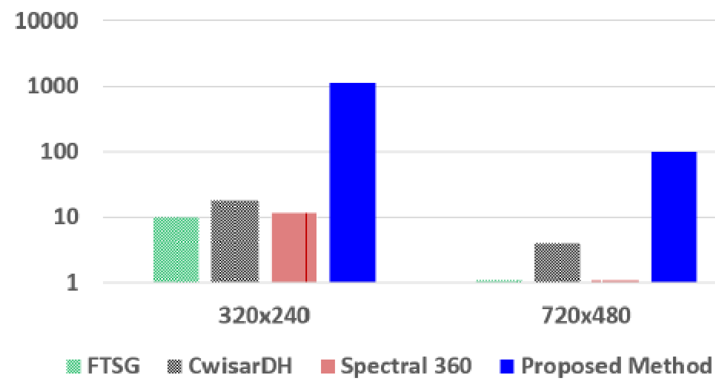



*Figure 8. Speed comparisons between the top 4 average ranking methods – [16], [18], [19] and the proposed technique.*

## A Full-Body Motion Calibration and Retargeting for Intuitive Object Manipulation in Immersive Virtual Environments

In this project a system is proposed to combine small finger movements with the large-scale body movements captured live from a motion capture system or provided by pre-programmed animation data. The strength of the proposed work over previous research is in the real-time performance of integrating small-scale finger and hand animation with the full-body skeletal animation. This provides a higher degree of immersion and interactivity when compared to more traditional virtual reality systems which use traditional user interfaces. A number of experiments are conducted with humanoid skeletons that are both similar to an actual humane - e.g. a SWAT officer, and those that are dissimilar - e.g. a Gremlin, to showcase the performance of the proposed approach.

### *Methodology and Approach*

Vicon Pegasus software is an excellent starting point for the reproduction of skeletal movements in virtual reality environments. Pegasus handles the retargeting and streaming of skeletal bodies into virtual environments, and is supported by several state-of-the-art game engines such as Unity and Unreal Engine 4. Using software such as Vicon Blade or Tracker combined with Pegasus offers a level of accuracy that is unrivaled when compared to similar marker-less setups.

However, these kinds of setups have difficulty in gathering data about joints that are too close in proximity; particularly the fingers. Therefore, markered setups are unequipped to handle tasks such as gesture detection without including additional sensors. With the addition of a Leap Motion Controller, the data specific to each finger can be blended to the Pegasus's body pose to fully recreate a skeletal body in a virtual environment. This Leap Motion Controller can be mounted either on a desk for sitting motions or directly on the HMD for standing motions in order to provide hand motions to all gestures that are performed in front of the user.

In order to include the LeapMotion data in an existing pose, such as the one provided live from a Vicon motion capture system via Pegasus or from pre-animated sequences, the data will need to be retargeted to match the hand. Due to the ambiguity of the user's hand dimensions, it is impractical to use a one-to-one retargeting of each bone's orientation. Instead, an Inverse Kinematics (IK) solver should be employed to guarantee that each of the finger's tip positions in the virtual skeleton is consistent with the leap motion data. To better match the leap motion data to the skeletal body, a calibration mode will be included to approximate the maximum and minimum distance from the base of each finger to the tip. These measurements will allow the leap motion data to be normalized and used to better match the finger lengths of the virtual skeleton. Implementation details are presented in [14].

Our platform of choice for the implementation of the virtual reality environment is Epic Game's Unreal Engine 4. The game engine, developed by Epic Games Inc., is comprised of an advanced graphics rendering engine, sound engine, and physics and animation engines. This game engine is capable of delivering unparalleled performance in 3D realistic gameplay, simulation and visualization [13]. Unreal Engine 4 (UE4), the latest major version of the engine, was released in April 2014. New to this release are several completely redesigned architectures that we are planning to utilize in this research.

We generated a range of qualitative results using two different skeletons in Figure 9. For each skeleton, we captured a rendering of the final pose for four different hand gestures without the leap motion (left), with the un-calibrated leap motion (middle), and with the calibrated leap motion (right). The vast difference in the uncalibrated and calibrated results reflects the need for the user-specific calibration data. With a one-to-one mapping from the user's hand to the skeleton's hand, a skeleton made specifically for the user’s hand dimensions would be required. However, any user’s hand can be re-targeted to any skeletal hand for fine motor controls and gesture detection with the calibration process.

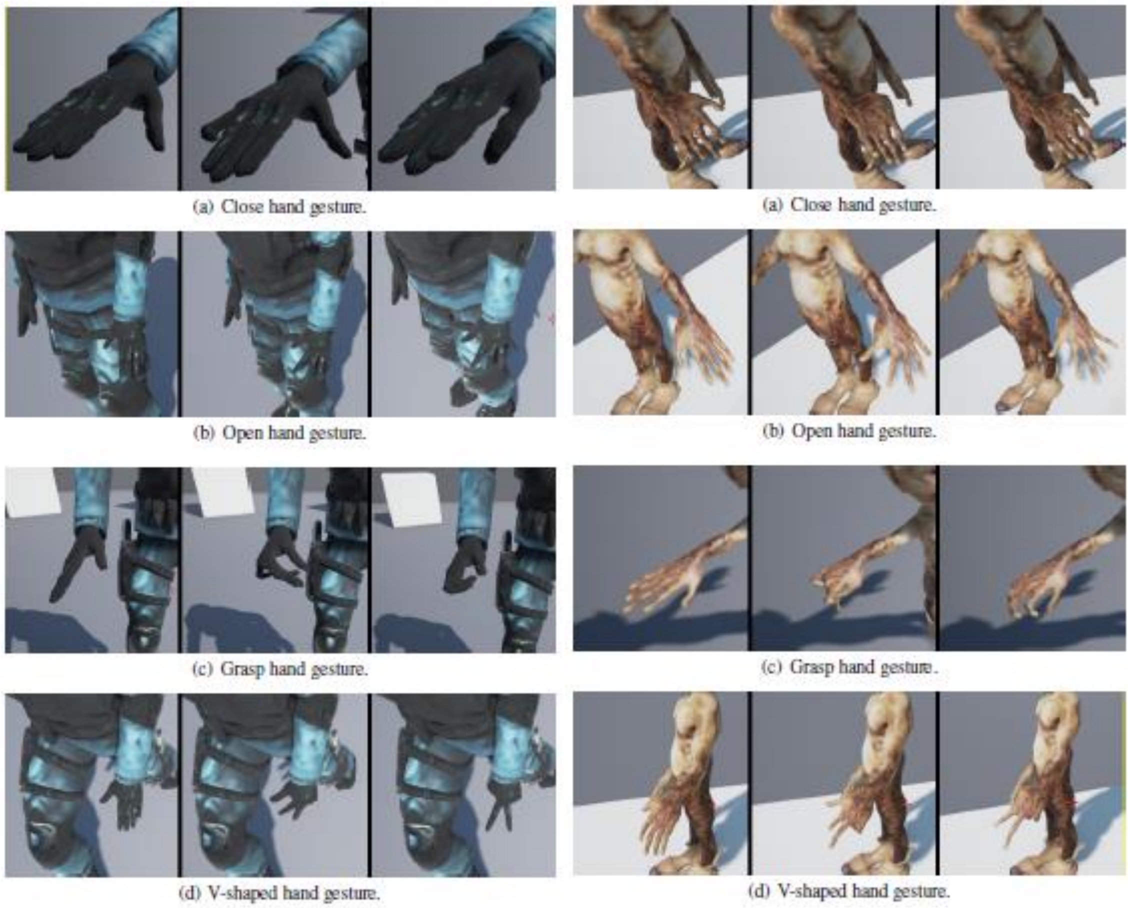



*Figure 9. Sample qualitative results achieved by the proposed approach using a humanoid skeleton with both similar hand proportions (left) and dissimilar hand proportions (right) when compared to the user. Images in each group from left: No leap motion data, un-calibrated leap motion data, and calibrated leap motion data.*

# Additional Projects of Interest

## InteractivityRelated Research Projects

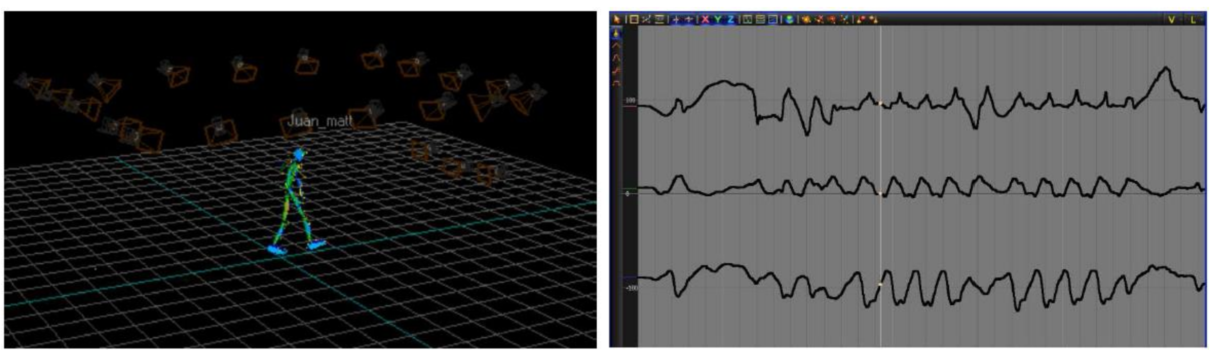
A significant research question that we are currently investigating addresses the problem of facilitating the interactivity and breadth of information provided in our virtual reality applications for seamless tele–operation of robotic agents. Therefore, we need to have reliable and robust means of manifesting the human user's actions with important and tangible effects into the virtual environment, and from there to the physically tele–operated environment (i.e. the real world where robotic agents operate).

To approach this problem, our team is mainly focusing on two research questions. First, we will approach the fusion of sensory information to design accurate models for the control of a remote agent by retargeting human gestures (or body part movements) on the control structure of the remote agent. Next, we will investigate and design higher–order models of the user's activity (and intent) by utilizing the theory of mind.

The robots first will be given training by observing retargeted movement patterns of the operator. When each structured activity (such as opening a door, fastening a screw, etc.) is learned by the robot, it will be able to take the perspective of its human operators later when it encounters similar activities to infer intent. This will further facilitate the interactivity and responsiveness of the robotic agents in support of the proposed framework.

### *Sensor Fusion for Tele-operation*

In this phase, we will investigate important factors in designing efficient modes for the tele–operation of remote agents from data supplied by our different sensory systems. Each of these sensors comes with a different rate of accuracy. Therefore, we will first establish ground-truth sequences of sensory information based on the most accurate sensory system in our portfolio.




(a) (b)

*Figure 10. Motion capture tracking data from Vicon T-160 camera system for a normal gait. (a) 3D reconstruction of the actor movements. (b) Joint-bone 3D rotational data for the ankle.*

We have acquired over 600 hours of motion capture sequences for a large number of poses and activities, such as regular walk, run, and jump cycles for both males and females. Figure 10 shows a 3D reconstruction of an actor's normal gait pattern captured by the Vicon T-160 camera system. The sub-millimeter accuracy of this camera system and its global independence with respect to the global coordinate system makes it a perfect candidate to be used as reference for calibration.

One important aspect of developing an affordable and tailorable virtual reality environment is the variety of costs for its different types of sensors. On the one hand, the Vicon T-160 motion capture cameras provide very accurate motion information, but at a very high cost, both in terms of budget and the expertise required to operate such a system. On the other, very low cost visual/range sensors such as Kinect cameras will provide motion data at a lower cost but with less accuracy. We propose to utilize the various sensory systems within this project to build models of higher order information, such as activities, intents, and overall scene models across different types of sensors.

To build the higher-order models we leverage the baseline positional data to validate the accuracy of other sensory systems and their applicability and efficiency for data collection. This part of our studies will bear a great amount of resemblance to the studies we have planned to conduct in support of the immersion and depth of information components.

By establishing higher order models of interaction across a variety of sensory systems, we can integrate on-board sensors from the robots (i.e. visual and range sensors), the virtual reality wearable sensors (i.e., the data gloves and head-mounted display), and the VR motion interfaces (i.e., feet and pose sensors), with the global sensors (i.e., the T-160 optical data and the Bonita video references). In this stage, models of interaction between the operator and the world will be built based on the accuracy and applicability of each sensory system to supply the tele–operation component.

Once we have suitable models of interaction designed and validated for each sensory system in the final framework, we will look at utilizing these models of interaction into suitable control mechanisms for tele–operation of the robotic agents. This phase of our research will be platform dependent, as different robots will have different modes of operation.

To control a humanoid robot with a skeletal structure similar to that of its operator, we will investigate different mechanisms to create robust retargeting functions (similar to those used in retargeting animation between different 3D models) to transfer the kinematic data from global and/or local (and wearable) sensors to the skeletal structure of the controlled robot. For non-humanoid robots, the retargeting models will be designed to suit the robot's actual mode of operation to control its motors by human kinetics.

### *Situational Awareness*

An important aspect of our proposed architecture is its capability to interact with human users and operators in an intuitive, robust and reliable manner. To this end, the proposed architecture needs to make intensive use of high-level intelligent tasks such as inferring user intentions, understanding contexts, as well as the ability to learn. Most of these tasks require the system to process information represented in the visual domain. Visual and range information may be combined to deliver more reliable patterns for processing by robots in our integrated system. Therefore, this phase will greatly benefit from the successful sensor fusion track.

A reliable and robust intelligent environment which is designed to co-operate with human inhabitants will need to posses, on some levels, a theory of mind [20]. This will enable the system to perceive human operators' actions, and based on prior experiences, to predict potentially useful intentions which the operators or cohabitants had in mind. We will statistically evaluate different cognitive models for efficient control of our robotic agents. This will provide particular prior information to augment our models of interaction to facilitate the implementation and development of the proposed theory of mind for intent recognition. Further use of prior information for augmenting the model are successfully used by Kelley et al. [8], while the HMMs are used to infer high-level cognitive functions such as intent recognition in the visual domain[9]. Moreover, we have planned to enhance these models by bringing more data rich sensory information and by developing data parallel algorithms to outsource the processing of this data to a GPU Accelerated platform.

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# Appendixes

## Appendix A – Equipment and Budget Description

**A. Senior/Key Personnel Salary & Wage**

None requested.

**B. Other Personnel Salary & Wage**

During the summer of 2015 the PI submitted a proposal to host one high school student and one undergraduate student at the CAVE lab at UHV to work with the equipment, on two research projects relevant to the research activities of the funded proposal. The funding for these students was supported by HSAP and URAP programs.

Student employees [*$5,300.32*]

**C. Equipment**

This proposal requested the funding for a unified tele-operations system in an immersive virtual reality environment to enable research in sensory data fusion and processing, heterogeneous computational architecture in support of such processes, and human studies of interaction and trust. Three components are essential to establish this research capability. Each one of the following components is integral to the research agenda and additional educational utilization. **<u>Together, Components 1-3, including modules A and B of Component 1, comprise a single system. On its own, an individual component would lack utility value.</u>**

*System Component 1: Virtual Reality Environment*

The Virtual Reality Environment will consist of two cooperative modules, a video capture module (A) and virtual reality client module (B).

<u>Module A – Vicon Bonita Video Capture Module</u>

The purpose of this module is to provide an accurate and robots sensory system in the visual domain. The research team is utilizing this component of the overall system to calibrate visual and non-visual tracking data acquired from T-160, Bonita, Virtual Glove, and other sensors to establish and validate models of activities, intentions, and tracking. This module consists of the following:

Four Bonita 720c Video Cameras ($10,152.22 total) will be necessary to generate models for the visual domain from motion data captured by UHV's existing T-160 system. They are also important in validation, to test for accuracy by cross-analysis with the T-160 motion data. The cameras operate with two Bogen super clamp short studs at $45 each ($90 total); four microball heads at $75 each ($300 total); and two light duty tripods at $225 each ($450 total) for mounting. [*$10,992.22*]

One Giganet LAB unit of $11,052.82 connects the T-160 optical cameras and the Bonita cameras to the host capture PC, essentially synchronizing the system via the Bonita to Giganet Cable and six-foot CAT5E cable (included in cost). [*$11,052.82*]

One Vicon Active Wand of $818.73 is necessary to calibrate the optical and reference cameras with 5-point accuracy. [*$818.73*]

One Quad Video PC of $2,922.86 is essential to capably process for the visual tracking system and to synchronize the Bonita video camera feed with the T-160 optical motion capture feed. The PC also requires two Dell 24-inch monitors ($532.17 total). [*$3,455.03*]

Vicon Nexus Software for this PC is included in Other Direct Costs, number 4, ADP/Computer Services. Installation and training costs from Vicon are included in Other Direct Costs, number 3, Consultant Services.

SUBTOTAL: $26,318.80

<u>Module B – Virtual Reality Client Module</u>

The purpose of this module is to facilitate the immersion of human users and operators into the virtual reality environment, and acquire motion patterns to enable interactions between virtual components of the system and virtual environment. This module consists of the following:

Two Alienware Aurora R4 Desktop computers ($7,339.96 total) are used exclusively to ensure that graphics and visualization processes run efficiently via their NVidia Graphics Processing Units. The desktops are needed to supplement the computers in the CAVE lab for general use by devoting these two computers to usage related especially to the research activities described in the technical portion of this report and, as applicable, to educational utilization. The set includes one of each component, such as the monitor, processor, keyboard, operating system, resource DVD, CD/DVD drive, warranties, and standard software, inclusive in the quoted price. [*$7,339.96*]

Two VirtualGlove Data Gloves (1 pair) of $5,000 per glove ($10,000 total) is an important tool for achieving precision in tracking minute movements of users' hands and fingers and transmitting this information. A shipping cost of $100 is included. [*$10,100*]

SUBTOTAL: $17,439.96

*System Component 2: Computational Backbone*

The purpose of this component is to support the computational needs for the machine learning and pattern recognition algorithms for building and evaluation of models of activities, intents and emerging interactions between virtual and physical worlds. This component consists of the following:

The Mercury GPU 408 Tower Server, pretested with x2 Tesla K80 Graphics Processing Units (GPUs), priced at $15,513.88, is crucial to handle processing for the high volume of data generated in the capture environment and building models for the autonomous agents. This tool will allow us to synchronize the robots with the virtual reality system as it performs modeling, training, and simulation processes. It consists of a tower, motherboard, keyboard, speakers, and 3-year warranty, among the items listed in the quotation. Important components include two Intel Xeon E5-2620, 6C, 2.40GHz processors and two K-80 NVidia Tesla, 24GB peripheral component interconnect express (PCI-Es). [*$15,513.88*]

SUBTOTAL: $15,513.88

*System Component 3: Autonomous Operational Robots*

This component is the physical component of the system which directly interacts with humans. As such each of the proposed robots are playing a major role in enabling our team to study various means of co-operation and tele-operation needed for this project. It consists of the following:

One PeopleBot at $31,995 along with its digital stereo camera ($9,995) and serial tether ($43) is central to our human studies. It will be used to map the environment and communicate with human operators. The autonomous capabilities of this robot and the ability to fully program it in both autonomous and tele-operated mode as well as its intuitive interfaces to communicate with humans will allow us to perform complex task and human studies to validate the human-machine trust and performance for complex scenarios. Shipping costs are $500. [*$42,533*]

One PatrolBot at $44,995 is a reliable research robot and comes with an arm ($14,995) and gripper ($350). It will be used for tasks such as calibrating the motion capture facility, tele-operation tasks, and autonomous tasks within the environment. Without this robot we could not perform complex tasks which require a functional robotic arm with the required degrees of freedom. Shipping costs are $500. [*$60,840*]

One NAO at $8,200 is a humanoid robot that will be used both for trust studies and tele-operation tasks. The anthropomorphic shape and feel of this robot and the 25 DoF afforded by NAO will be an instrumental component for human studies and validation of human-robot trust models. [*$8,200*]

SUBTOTAL: $111,573.00

The four systems are essential to completely outfit UHV and its students with the capability to carry out the proposed research. In sum, the proposed system is comprised of a system of interconnected components, namely: the virtual reality environment (component 1), the computational backbone (component 2), and autonomous robotics agents (component 3). The computational backbone will interact directly with the other two components and will be in charge of computational modeling of calibration, machine learning, and sensory data integration as well as facilitating the interactions between physical and virtual components of the system. The Virtual Reality modules of the system will locally process the sensory data from client-side and the environment through the capture component. Finally, the robotics agents will be the physical component of the system which will interface with the other two components to facilitate the human robot interaction and help with our studies of human-robot trust as well as performance of such interactions.

TOTAL EQUIPMENT COSTS: $170,845.64

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**D. Travel**

None requested.

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**E. Participant/Trainee Support Costs**

None requested.

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**F. Other Direct Costs**

*1. Materials and Supplies*

One Alienware 17 (210-ACKC) Laptop of $1,812.99 is requested for remote applications, and an external harddrive of $69.99. It is essential to the outreach and dissemination components of any research to provide demonstrations and present findings, as Dr. Tavakkoli intends to do at high schools and academic conferences. It will be used in tandem with the requested equipment only. [*$1,882.98*]

For our remote applications Alienware 17 (210-ACKC) laptop, we request a travel briefcase of $99.99, already included in the quotation. The Vindicator briefcase is made specially to fit this laptop and provides a high quality of protection. [*$99.99*]

SUBTOTAL: $1,982.97

*2. Publication Costs*

None requested.

*3. Consultant Services*

Installation and training for the Vicon Bonita Video Capture system is necessary for a Vicon engineer to spend two days at UHV to install and train Dr. Tavakkoli in the use of the system. [*$0*]

SUBTOTAL: $0.00

*4. ADP/Computer Services*

The Vicon Nexus Software of $15,871.20 will be operated on the Quad Video PC which allows for system calibration, data capture, processing, and exporting to other software. [*$15,871.20*]

SUBTOTAL: $15,871.20

*5. Special Circumstances*

Originally a 4DoF gripper for the robotic arms (originally quoted at $2,995) was requested. After the grant was awarded, the vendor and manufacturer informed the PI that the 4DoF gripper is going through a redesign phase. The gripper redesign was not completed by the end of the performance period. The PI contacted the program officer and received approval to acquire a 2DoF Gripper (quoted at $360). The PI received permission to utilize the remainder of the funds originally allocated for the 3DoF gripper on purchasing an additional Alienware Area 51 desktop ($2,249.99) for the Virtual Reality client module. [*$2,249.99*]

SUBTOTAL: $2,249.99

TOTAL OTHER DIRECT COSTS: $ 20,104.16

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**G. Direct Costs (Total)**

**$196,250.12**

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**H. Indirect Costs**

None requested.

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**I. Total Direct and Indirect Costs (Total Federal Request)**

## $196,250.12

# Appendinx B – Final Budget

## Equipment

| Description | Manufacturer/Vendor | Costs | Acquisition Special Circumstance |
|---|---|---|---|
| **Vicon Bonita Video Capture & Virtual Reality Client Modules** | | | |
| Bonita 720c Video Cameras | Vicon | 10,152.22 | |
| Bogen super clamp short studs | Vicon | 90.00 | |
| Microball heads | Vicon | 300.00 | |
| Light duty tripods | Vicon | 450.00 | |
| Giganet LAB unit | Vicon | 11,052.82 | |
| Vicon Active Wand | Vicon | 818.73 | |
| Quad Video PC | DELL | 2,922.86 | |
| Dell 24-inch monitors | DELL/Vicon | 532.17 | |
| Alienware Aurora R4 Desktop computers | Dell Marketing Lp | 6,859.98 | |
| Dell UltraSharp 24-inch monitors | Dell/Dell Marketing LP | 479.98 | |
| VirtualGlove RH | Virtual Realities | 5,000.00 | |
| VirtualGlove LH | Virtual Realities | 5,000.00 | |
| Shipping & handling | N/A | 100.00 | |
| **Computational Backbone (Quantum Server, Processors, GPUs)** | | | |
| Mercury GPU408 4U Tower Server with Three-Year Standard Warranty | Advanced Hpc Inc | 14,569.56 | |
| Mouse & Keyboard | Advanced Hpc Inc | 28.41 | |
| UltraSharp 24 Inch VIS monitor | Advanced Hpc Inc | 261.36 | |
| Microsoft Window 7 Professional | Advanced Hpc Inc | 153.41 | |
| 4T SATA 6Gb/s 3.5 Inch 7.2 RPM Disk Drive | Advanced Hpc Inc | 251.14 | |
| Shipping & handling | N/A | 250.00 | |
| **Autonomous Robotics Agents (PeopleBot, PatrolBot, NAO)** | | | |
| PeopleBot | Adept Mobile Robots | 31,995.00 | |
| Digital stereo camera | Adept Mobile Robots | 9,995.00 | |
| Serial tether | Adept Mobile Robots | 43.00 | |
| Shipping & handling | Adept Mobile Robots | 500.00 | |
| PatrolBot (VSLAM PatrolBot w/Color Stereo) | Adept Mobile Robots | 44,995.00 | |
| Arm (Premium Arm (DX/AT)) | Adept Mobile Robots | 14,995.00 | |
| Gripper (4 DOF Gripper for Gamma 1500) | Adept Mobile Robots | 350.00 | |
| Shipping & handling (freight) | Adept Mobile Robots | 500.00 | |
| NAO | RobotsLAB US Inc. | 7,990.00 | |
| Shipping & handling | N/A | 354.00 | |
| **Discount** | N/A | -144.00 | |

| Materials and Supplies | | | |
|---|---|---|---|
| Alienware 17 (210-ACKC) Laptop | Dell Marketing Lp | 1,812.99 | |
| External DVD | Dell Marketing Lp | 69.99 | |
| Travel briefcase (Alienware Vindicator Briefcase) | Dell Marketing Lp | 99.99 | |
| **Consultant Services** | | | |
| Installation & training for the Vicon Bonita Video Capture | Vicon | 0.00 | |
| **ADP/Computer Services** | | | |
| Vicon Nexus 2.0 Standalone | Vicon | 15,871.20 | |
| **Special Circumstances** | | | |
| Alienware Area 51 Desktop | Dell Marketing Lp | 2,249.99 | Please see section **F.5** on page 23 |
| | | | |
| | **Equipment Total** | **$ 190,949.80** | |

## HSAP and URAP Summer 2015 Apprenticeships

| Student employees | Salary & Wages | Fringe | Totals |
|---|---|---|---|
| Melissa Clark (URAP) | $ 2,360.00 | $ 192.81 | $ 2,552.81 |
| Lucas Kabela (HSAP) | $ 2,540.00 | $ 207.52 | $ 2,747.52 |
| | | | **$ 5,300.33** |

# Appendix C – Evidence of UHV's Additional Support

**Evidence of UHV's Current/Future Financial Support of Proposed Research & Education**

The following items are on order or are scheduled to be ordered using HEAF funds and are scheduled for installation and usage for Fall 2014. They can be used within UHV's existing CAVE lab and its current system. Other technologies and equipment currently in place at UHV's CAVE lab are named in the Project Narrative. These costs do not include all potential maintenance and operation costs or other costs that may be requested from HEAF funds in the coming years—only those for which dedicated funding already is arranged.

Two Virtuix Omni VR Threadmill (omni-directional motion interfaces) of $500 each ($1,000 total) will allow users to move freely and naturally in virtual environments, thereby enabling us to research human studies in trust, comfort, and performance with the equipment. [*$1,000*]

Two Low-latency Oculus Rift v2 goggles (head-mounted displays) of $350 each ($700 total) are integrated within UHV's existing Unreal 4.x game engine licenses and subscriptions. For the purposes of this research, they are necessary to immerse the user into the virtual world without requiring the development of an Application Programming Interface. [*$700*]

TOTAL INSTITUTIONAL COMMITMENT: $1,700.00